

ARDEC Solid Gun Propellant Shock Initiation Sensitivity Test

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ABSTRACT

NOL large card gap test is not suitable to assess the shock sensitivity of granular propellant beds made of large grains. The result can be strongly influenced by the heterogeneity of the bed. A new small scale gun propellant shock sensitivity test has been developed at ARDEC. This test is a sensitive discriminator to assess gun propellant shock sensitivity.

INTRODUCTION

Shock-to-detonation sensitivity is one of the most important safety/hazard properties of energetic materials. Traditionally, this property is evaluated by the NOL large card gap test shown in the TB 700-2, the Department of Defense Explosive Hazard Classification Procedures. The large card gap test was developed to evaluate the shock sensitivity of homogeneous material such as a monolithic block of high explosive. This same test is now also used to evaluate the shock sensitivity of granular gun propellant beds which are highly heterogeneous. There have been some doubts in the safety community about the applicability of the large card gap test to assess the shock sensitivity of the granular gun propellants. As a part of ARDEC's gun propellant effort to investigate the basic material properties of gun propellants, the problem of using large card gap test to evaluate gun propellants, in particular for large caliber guns, was investigated, and an alternate new gun propellant shock sensitivity test is developed. The results of this study are reported in this paper.

LARGE CARD GAP TEST DEFICIENCY

Two test series were conducted to illustrate the deficiency of using the NOL large card gap test to assess the shock sensitivity of gun propellants. In the first test series, a large caliber gun propellant sample was loaded into three large card gap test fixtures as shown in Figure I. In the first fixture, no special arrangement was made on the propellant bed. In the second fixture, the grains at the top most layer were oriented sideways, and in the third fixture, the grains at the top most layer were oriented vertically. Additional grains were used to fill any void in the first layer in the second and the third fixtures. A small amount of grease was smeared on the top layer of grains and filled some of the voids among grains, to further improve the shock transmitting coupling between the pentolite booster and the grains in the second and the third fixtures. No cards were used in these tests. The results were very different. The fixture with grains oriented sideways which has the maximum contact area with the booster, had the most violent reaction: the witness plate was punctured and shattered. The fixture with the grains oriented vertically had a less violent reaction, a significant deformation of the witness plate occurred. The fixture with normal loading procedure had the least violent reaction, it only had

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE AUG 1994		2. REPORT TYPE		3. DATES COVERED 00-00-1994 to 00-00-1994	
4. TITLE AND SUBTITLE ARDEC Solid Gun Propellant Shock Initiation Sensitivity Test				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Armament Research, Development and Engineering Center,Picatinny Arsenal,NJ,07806-5000				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.					
14. ABSTRACT see report					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 8	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

a relatively shallow deformation in the witness plate. These results suggest that the shock transmitting coupling between the pentolite driver and the propellant grains has a strong effect on the shock initiation and subsequently the reaction of the propellant bed in this test configuration.

Figure 1. Test Setups of Three Loading Arrangements.

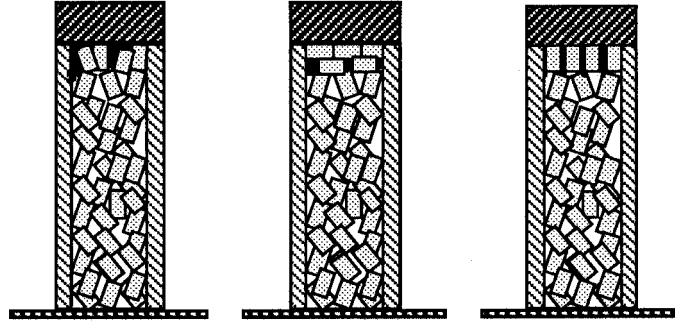


Figure 1. Test Setups of Three Loading Arrangements.

To find out the shock transmitting coupling problem between the explosive driver and a heterogeneous energetic material bed in the NOL large card gap test, we conducted a second test series.

in this test series, we manufactured four energetic material pellets of a same formulation. The pellet length to diameter ratio is one in these four samples. The large card gap test results are shown in Figure 2. The card thickness decreases as the pellet size increases. The apparent result suggests that the samples becomes less shock sensitive as the grain size increases. Since these four samples are made of the same chemical formulation, their shock sensitivity, which is a formulation determined material property, should be the same. So the apparent change of shock sensitivity of these tests has to be the effect of the grain configuration. The propellant bed of small grains has a larger number of contacts, thus a better shock transmitting coupling, to transmit shock among grains in a given cross-section of the test fixture.

Figure 2. Large Card Gap Test Results

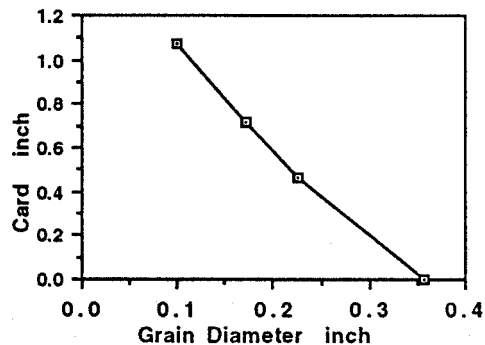


Figure 2. Large Card Gap Test Results

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This is evident in the photograph of these samples in a container which has the same size as the large card gap test fixture shown in Figure 3.

From these results, we conclude that the NOL large card gap test may be useful to evaluate gun propellants of small grains, but it is not suitable to assess large caliber gun propellants whose size is relatively large in comparison with the fixture size. The apparent test result is simply a measure of the heterogeneity of the propellant bed instead of the true shock sensitivity of the propellant. For this reason, we suggest an alternate test as shown below.

Figure 3. Photograph propellant grains of four different sizes.

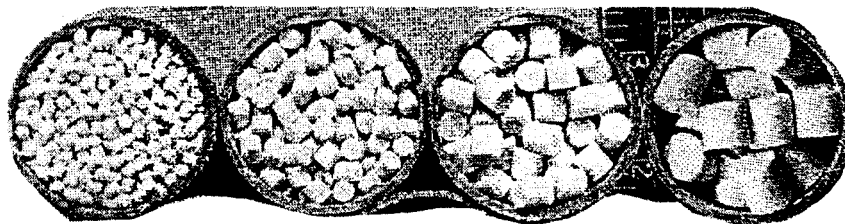


Figure 3. Photograph propellant grains of four different sizes.

Gun Propellant Shock Initiation Sensitivity Test

This test is basically a modified card gap test. The difference is that we eliminate the heterogeneity effect of a propellant bed by measuring directly the shock sensitivity property of the propellant grain itself. The shock sensitivity of a propellant bed certainly is different from a single propellant grain. But in a propellant bed which constitutes many single propellant grains, the shock sensitivity of each individual grain shall influence the shock sensitivity of the propellant bed.

Test Setup.

A sketch of the test setup for the solid gun propellant shock sensitivity test is shown in Figure 4. The test sample is contained in a 15.2 cm (6 inch) long, 2.54 cm (1 inch) diameter, mild steel cylinder with a hole drilled axially. Since propellant grains are not perfect straight cylinders, the drill bit size which is next size larger than the measured grain diameter, is used to drill the hole to ease the loading processes. To lower the machining cost, we also have drilled out a thick wall steel tube, instead of a solid rod, to make the fixture. The steel fixture was filled with stacked propellant grains. The ends of each grain were machined flat to insure good contact between grain ends. To avoid any possible air gap between grains during assembly and handling, the ends of each grain were slightly wetted with acetone during the assembling process, and a 4.5 kg (10 pounds) weight was placed on the propellant grain column inside the tube for about a minute. Small (No. 50 drill) holes are drilled through the steel tube wall along the length of the propellant grain column. Low cost one mm diameter, plastic optical fibers (Reference 1) are inserted in these holes to measure the time of arrival of the luminous reaction front. Since there is not much significant velocity change at the initiation end of the sample, a wide spacing between the first and second fiber optics is acceptable. The event is fairly bright, no special procedure is needed to prepare the ends of the plastic optical fiber except to use a sharp razor blade to make a clean square cut. Fast response (nanoseconds) photodiodes are used to convert the light signals into electric signals which are recorded in a digital oscilloscope. The bright reaction front is a more sensitive property to measure in a decaying propagating detonation wave than the shock front, as it decays at a much faster rate than the shock front in a decoupled (decaying) detonation front. In addition, the plastic optical fiber is much cheaper than commercial self-shortening or piezoelectric time of arrival pins.

The upper most propellant grain is shock initiated by a detonating 9.5 mm (3/8 inch) diameter and 9.5 mm (3/8 inch) tall PBXN-5 explosive booster at a density of 1.65 gm/cc. PBXN-5 explosive was chosen for its relative quick initiation-to-detonation property so that a reproducible shock will be generated. In some tests, just like any card gap test, polymethylmethacrylate (PMMA, acrylic, Plexiglas) cards may be placed in between the PBXN-5 booster and the propellant sample to attenuate the shock so that most sensitive samples can be discriminated from several sensitive samples by the number of cards to attenuate the shock to a level to generate a decaying reaction.

Figure 4. Gun Propellant Shock Sensitivity Test setup.

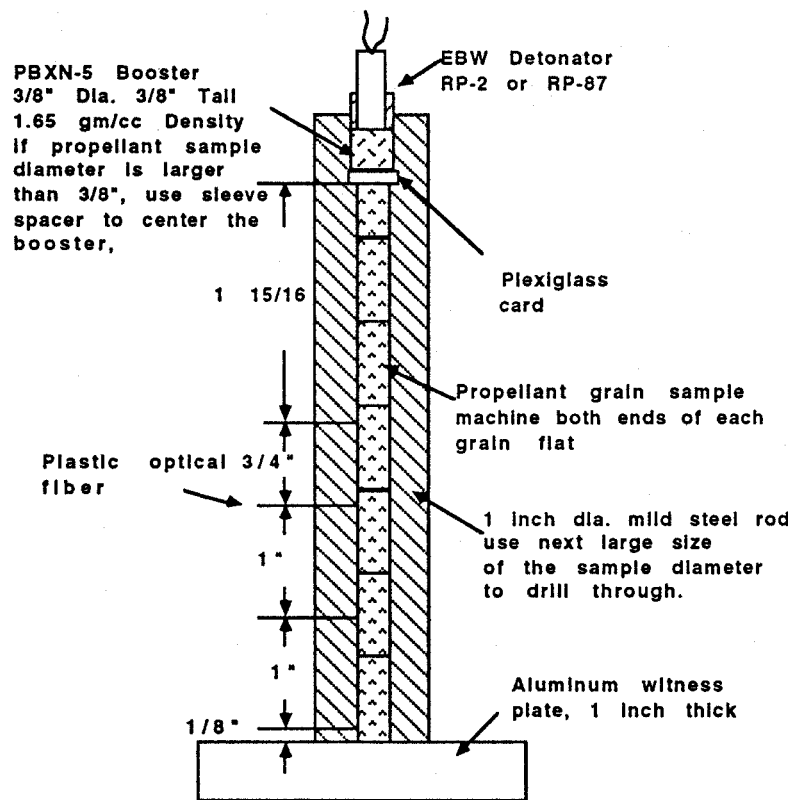


Figure 4. Gun Propellant Shock Sensitivity Test setup.

The test fixture is oriented vertically and placed on an one inch thick aluminum witness plate to provide secondary information of the reaction level.

To illustrate the usefulness of this test, the results of two test series are shown below. In the first series we tested four gun propellant samples made of different formulations. They all pass the NOL large card gap test requirement and are classified as 1.3 explosive material. In the second test series, three experimental propellant samples were made of same chemical ingredients, except the chemical composition were slightly modified in each case.

Test Results.

Figure 5A shows the time of arrival data of three samples. No card was used in this series. Sample A is obviously more shock sensitive than samples B & C. The sample A's reaction front velocity is steady which indicates a detonation, while the propagation velocity of samples B & C are both decaying. Figure 5B shows the time of arrival data of samples A and D with a 0.010 inch thick card between the N-5 booster and the propellant sample. While the sample A propagation velocity decays in this test, the sample D is still propagating at a steady velocity. This indicates that Sample D is more shock sensitive than Sample A is.

Figure 5. Reaction Front Time of Arrival Results of Four Propellants.

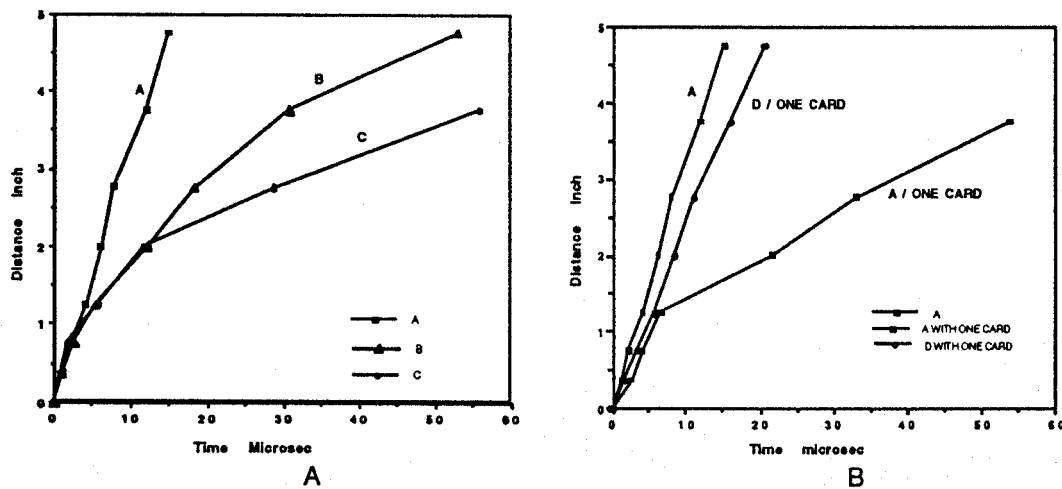


Figure 5. Reaction Front Time of Arrival Results of Four Propellants.

The results of second test series are shown in Figure 6. The three propellants samples have identical chemical ingredients but their composition were not the same. Their grain configurations are Identical. Samples E and F propagate steadily while the sample G is decaying. This indicates that the sample G is less shock sensitive than samples E and F.

Figure 6. Time of Arrival Data of Three Samples of Same Chemical ingredients.

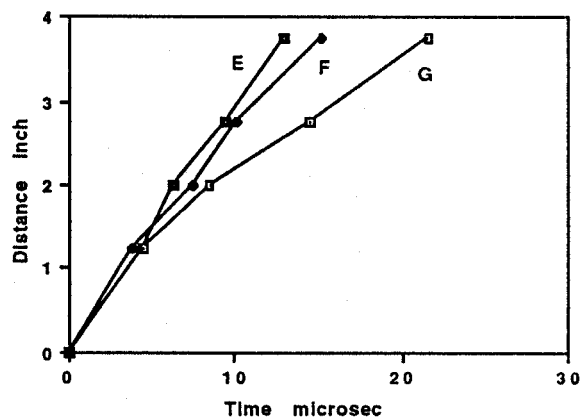


Figure 6. Time of Arrival Data of Three Samples of Same Chemical ingredients.

For two reasons, we do not rely on the aluminum witness plate information solely to determine the relative violence of reaction which is influenced by the shock sensitivity of the samples. The reaction front propagation velocity data is easier to interpret to make an accurate evaluation. A dent can be easily misinterpreted by inexperienced persons. As an example, two witness plate dents are shown in Figure 7. One is produced by a detonating sample and the other by a decaying sample. The “dent” produced by the latter sample was simply a mechanical deformation formed by the propellant sample being pushed into the soft aluminum witness plate from explosive loading at the initiation end.

Figure 7. Witness Plates of a Detonating Sample and a Decaying Sample.



Figure 7. Witness Plates of a Detonating Sample and a Decaying Sample.

This gun propellant shock test was developed to provide a more reliable guideline to our test range personnel on any special precaution to handle a particular experimental propellant. Certainly the 2 7/8 inch and 8 inch diameter super gap tests can overcome the NOL large card gap test problem described above. However, both tests need a large amount of sample which may be not economically feasible during the development stage of any new propellant. Although the shock sensitivity of a propellant bed may be different from the shock sensitivity of a propellant grain, the shock sensitivity information of a single grain is still useful to workers prior to any full scale safety/hazard classification test.

CONCLUSION

NOL large card gap test is not suitable to assess the shock sensitivity of granular propellant beds made of large grains. The result can be strongly influenced by the heterogeneity of the bed. A small scale gun propellant shock sensitivity test has been developed. The relative shock sensitivity among samples is determined by the behavior of the propagating reaction front. For a given shock stimuli, a sensitive sample generates a steady propagating reaction front, while the less shock sensitive sample generates a decaying velocity reaction front. This test is a sensitive discriminator to assess gun propellant shock sensitivity. Based on limited data to-date, it is suggested to use a 7.6 mm (0.3 inch) thick PMMA card to discriminate very sensitive gun propellant. If the reaction front propagates steadily at this gap or larger, it is suggested to interim classify it Hazard Division 1.1. If the reaction front velocity is decaying, it is suggested to interim classify it Hazard Division 1.3.

ACKNOWLEDGEMENT

The author wish to thank Messrs B. Strauss, S. Moy, and J. Shin for preparing the samples and conducting the tests.

REFERENCE

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